Appendix A1:
A Systems View of the Modern Grid

SELF-HEALS

Developed for the U.S. Department of Energy
Office of Electricity Delivery and Energy Reliability
by the National Energy Technology Laboratory
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NETL

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EXECUTIVE SUMMARY

The systems view of the modern grid features seven principal characteristics. One of those characteristics is '*Self heals'.* What that means and how we might attain that characteristic is the subject of this paper.

Figure 1: The Modern Grid Systems View provides an "ecosystem" perspective that considers all aspects and all stakeholders.

In the context of the modern grid, "self-healing" refers to an engineering design that enables the problematic elements of a system to be isolated and, ideally, restored to normal operation with little or no human intervention. These self-healing actions will result in minimal or no interruption of service to consumers. It is, in essence, the modern grid's immune system.

The modern, self-healing grid will perform continuous, online self-assessments to predict potential problems, detect existing or emerging problems, and initiate immediate corrective responses. The self-healing concept is a natural extension of power system protective relaying, which forms the core of this technology.

A self-healing grid will frequently utilize a networked design linking multiple energy sources. Advanced sensors on networked equipment will identify a malfunction and communicate to nearby devices when a fault or other problem occurs. Sensors will also detect patterns that are precursors to faults, providing the ability to mitigate conditions before the event actually occurs.

The self-healing objective is to limit event impact to the smallest area possible. This approach can also mitigate power quality issues; sensors can identify problematic conditions and corrective steps can be taken, such as instantly transferring a customer to a “clean” power quality or source.

A simplified example of the self-healing concept, illustrated in Figure 2 below, shows two power lines having many “intelligent switches” (noted as “R”) located along the circuit. This diagram illustrates the intelligent switching feature of self-healing, which can maintain power to a maximum number of customers by instantaneously transferring them to an alternate energy source.

Alternate energy sources may include circuit ties to other feeders or to distributed energy resources (DER) such as energy storage devices and small electrical generators (powered by both renewable and non-renewable fuels). Demand response (DR) can also be a tool in matching load to generation in the self-healing process.

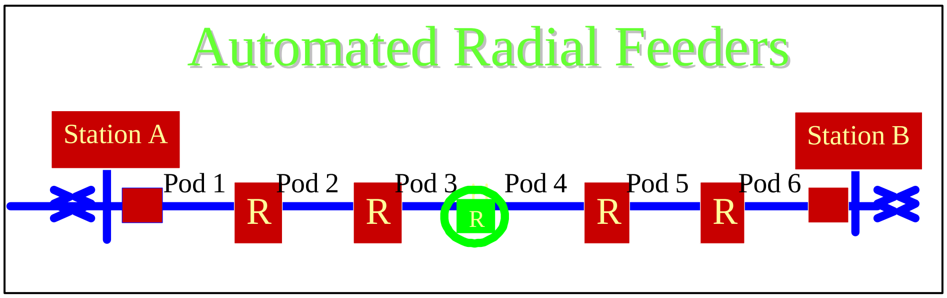


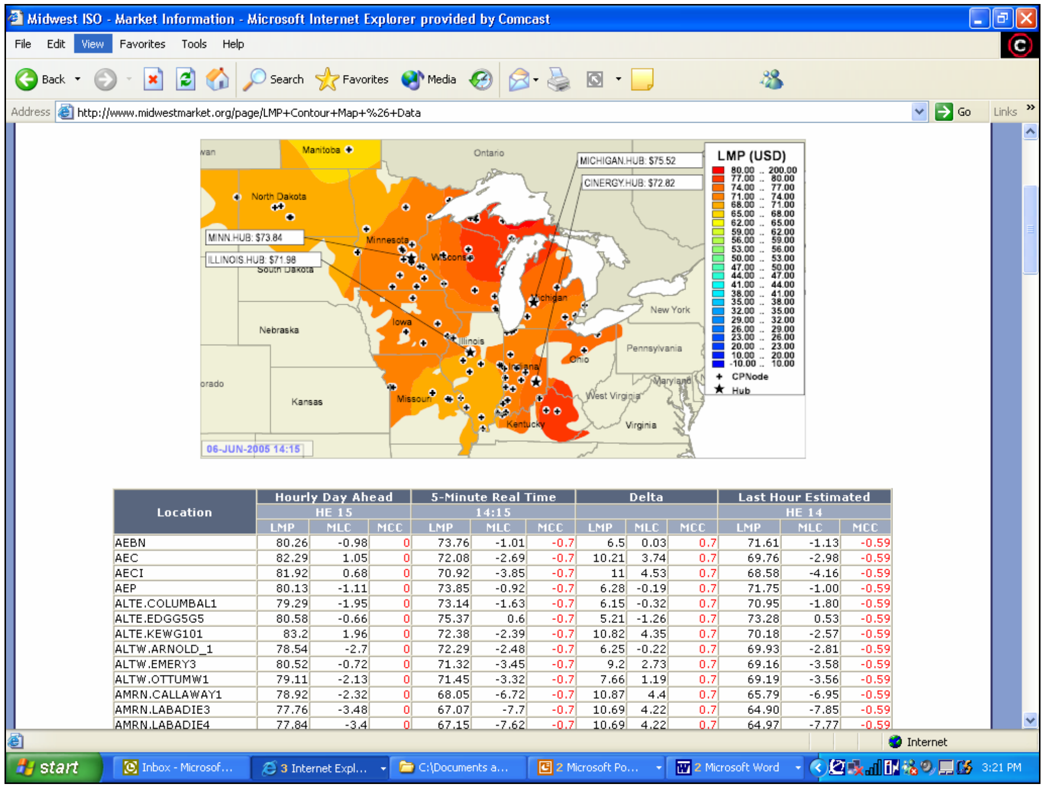
Figure 2: Automated radial feeders schematic. Image courtesy of DV2010.

The modern electrical grid will know a great deal about problems affecting its operation. One of the keys to self-healing is the utilization of a wide assortment of information gathered from modern grid devices to enable rapid analysis and initiation of automatic corrective actions,

Fault locations, circuit configuration changes, voltage and power quality problems and other grid abnormalities can be quickly discovered and corrected. High-risk areas, as well as individual pieces of equipment, can be analyzed for immediate action. Also advanced models can provide new visualization tools revealing congestion issues, overlays of failure probabilities, and resulting threat levels.

Another element of self-healing is the avoidance of high-risk situations. When impending weather extremes, solar magnetic disturbances, and real-time contingency analyses are incorporated into a probabilistic model, grid operators will be better able to understand the risks of each decision they may make, as well as ways to minimize those risks. In such applications, the expected volume of real-time data is high. And it will be necessary to integrate those data up to the control area, regional transmission organization level, NERC Region level, or the entire national grid, including its interconnections with Canada and Mexico.

Figure 3 below illustrates one way to convey broad information (relative energy prices, in this case) at a glance. Similar presentation techniques supporting self-healing are possible, showing relative risk, overloads, voltage violations, or other applicable metrics.



Location	Hourly Day Ahead HE 15			5-Minute Real Time 14:15			Delta			Last Hour Estimated HE 14		
	LMP	MLC	MCC	LMP	MLC	MCC	LMP	MLC	MCC	LMP	MLC	MCC
AEBN	80.26	-0.98	0	73.76	-1.01	-0.7	6.5	0.03	0.7	71.61	-1.13	-0.59
AEC	82.29	1.05	0	72.08	-2.69	-0.7	10.21	3.74	0.7	69.76	-2.98	-0.59
AECI	81.92	0.68	0	70.92	-3.85	-0.7	11	4.53	0.7	68.58	-4.16	-0.59
AEP	80.13	-1.11	0	73.85	-0.92	-0.7	6.28	-0.19	0.7	71.75	-1.00	-0.59
ALTE.COLUMBAL1	79.29	-1.95	0	73.14	-1.63	-0.7	6.15	-0.32	0.7	70.95	-1.80	-0.59
ALTE.EDGG5G5	80.58	-0.66	0	75.37	0.6	-0.7	5.21	-1.26	0.7	73.28	0.53	-0.59
ALTE.KEWG101	83.2	1.96	0	72.38	-2.39	-0.7	10.82	4.35	0.7	70.18	-2.57	-0.59
ALTW.ARNOLD_1	78.54	-2.7	0	72.29	-2.48	-0.7	6.25	-0.22	0.7	69.93	-2.81	-0.59
ALTW.EMERY3	80.52	-0.72	0	71.32	-3.45	-0.7	9.2	2.73	0.7	69.16	-3.58	-0.59
ALTW.OTTUMW1	79.11	-2.13	0	71.45	-3.32	-0.7	7.66	1.19	0.7	69.19	-3.56	-0.59
AMRN.CALLAWAY1	78.92	-2.32	0	68.05	-6.72	-0.7	10.87	4.4	0.7	65.79	-6.95	-0.59
AMRN.LABADIE3	77.76	-3.48	0	67.07	-7.7	-0.7	10.69	4.22	0.7	64.90	-7.85	-0.59
AMRN.LABADIE4	77.84	-3.4	0	67.15	-7.62	-0.7	10.69	4.22	0.7	64.97	-7.77	-0.59

Figure 3: Advanced visualization gives operators detailed data about the workings of the modern grid. Image courtesy of Midwest Independent Transmission System Operator, Inc. For informational purposes only.

The modern grid will enhance self-healing functions in the transmission grid and will extend those functions to the distribution level. For example, Wide Area Monitoring Systems (WAMS), utilizing phasor measurement units, combined with advanced state estimation algorithms run on high-speed computers, could control Flexible Alternating Current Transmission System (FACTS) devices to prevent or mitigate a developing system collapse. And dynamic islanding using DER devices and intelligent switching is but one example of self-healing at the distribution level—there are many others.

While advanced sensing, analysis, protection and control are important elements of a self-healing grid, so too is a robust T&D infrastructure. High-capacity circuit ties joining major Regional Transmission Organizations (RTOs) allow for inter-region power flows in an emergency. But if this power transfer capability is not adequate, then upgrades to higher capacity or the construction of new tie lines is required. This infrastructure improvement would also result in more robust energy markets, allowing less expensive generating unit power to flow to areas of high-cost congestion.

This paper explores how the modern grid will act to reduce the number and duration of outages, minimize restoration times and reconfigure the grid to produce optimum reliability and quality of service. **All these features are rolled up to a common name that we call the 'Self-healing' characteristic of the Modern Grid.**

In this paper we address these following important topics:

- The current and future states of the grid
- The requirements of a "Self-healing' grid
- The barriers to implementing a "Self-healing" grid
- The benefits in achieving a "Self-healing" grid
- Recommendations for moving forward in this endeavor

Although this whitepaper can be read on its own, it supports and supplements "A Systems View of the Modern Grid," an overview prepared by the Modern Grid Initiative (MGI) team.

CURRENT AND FUTURE STATES

CURRENT STATE

Transmission

Today's transmission grid was designed with many self-healing features. Auto-reclosing and auto-sectionalizing are common techniques employed to maintain loads under adverse conditions. The network mesh design of the transmission system is in itself self-healing due its built-in redundancy and such protective relaying features as high-speed reclosing and single-phase tripping.

System planners have historically modeled the transmission system to verify that, under a normal system configuration, assumed loads could be met even during expected peak conditions. In addition, planners ensured that these same loads could be met even with the failure of single, and in some cases, multiple lines or components.

Sophisticated protective relaying schemes are in place to monitor system conditions and take corrective action should specific parameters exceed their limits. Transmission lines and equipment are relayed out (i.e., tripped) when conditions require, and most loads normally are not impacted by a single fault because the system can tolerate a single contingency. Substation automation and new intelligent electronic devices have taken transmission protection to the next level.

The design of the current transmission system incorporated the notion of self-healing many years ago and utilized the technologies, processes, and techniques available at the time. Significant advances in digital technologies, correctly applied, will dramatically improve this self-healing capability.

Distribution

At the distribution level, new distribution automation (DA) technologies are being deployed to increase reliability and efficiency. DA applications improve the efficiency of system operation, reconfigure the system after disturbances, improve reliability and power quality, and identify and resolve system problems. Many DA applications can also be extended to coordinate with customer services, such as demand-response, and distributed energy resources (DER). In addition, distribution systems that include feeder-to-feeder backup allow enhanced DA functionality. These new approaches are directionally consistent with the vision of the self-healing feature of the modern grid. DA is integral to the concept of a self-healing grid.

The current distribution system, without distributed resources and without an intelligent networked configuration, has been handicapped from a self-healing perspective. Today most DA and substation automation (SA) systems are applied at a local level, using local information for decision-making. The basic design of the integrated transmission grid—many geographically diverse generation sources feeding a high-voltage networked transmission system—is conducive to self-healing. On the other hand, the fundamental design of today's distribution systems cannot, in most cases, incorporate the depth of self-healing found on today's transmission systems.

FUTURE STATE

The self-healing feature of the modern grid, at both the transmission and distribution levels, will advance from its current state by integrating advanced capabilities in the following areas:

Look Ahead Features

- Analytical computer programs, using accurate and near real-time state estimation results, will identify challenges to the system, both actual and predicted, and take immediate automatic action to prevent or mitigate the event. Where appropriate, and when time allows, these algorithms will also provide options for the system operator to manually address the challenge.
- Probabilistic risk analysis, also in near real time, will identify risks to the system under projected normal operating conditions, single failures, double failures, and out-of-service maintenance periods.
- Load forecasting will be greatly improved to support more accurate look-ahead simulations. These simulations will be performed over various time horizons—minutes, hours and days in support of operations; monthly, quarterly, and annually to support O&M planning activities; and longer range to support investment decisions.

Monitoring Features

- Real-time data acquisition, employing advances in communication technology and new, lower-cost smart sensors, will provide a significantly larger volume and new categories of data, such as wide-area phasor measurement information. This dramatic increase in the volume of real-time data, combined with advanced visualization techniques (see Appendix B 5, Improved Interfaces and Decision Support), will enable system operators to have an accurate understanding of the power delivery system's health.
- By analyzing equipment condition data - including high frequency emission signatures—condition monitoring technologies will provide additional perspectives on the consequences of potential equipment failures.
- State estimators will take advantage of advanced data acquisition technologies and powerful computers that enable them to solve problems in seconds or less.

- Advanced visualization techniques will consolidate data and present the appropriate information to operators in easily understood formats.
- Command and control centers at the regional level for transmission operations and at more local levels for distribution operations will serve as hubs for the new self-healing features.

Protection and Control Features

- Advanced relaying will be employed to communicate with central systems and adapt to real-time conditions.
- High-speed switching, throttling, modulating, and fault-limiting devices will dynamically reconfigure the grid, including faster isolation and sectionalization as well as rapid control of real and reactive power flows in response to system challenges.
- Intelligent control devices, such as grid friendly appliances, will modulate load requirements in response to dynamic grid changes

Distributed Technology Features

- Distributed generation and energy storage technologies will be widely deployed, particularly at the distribution level, and dispatched as system resources in response to self-healing needs. DER will also be used to support local circuit needs.
- Transformation of the distribution system from a radial design to an intelligent network design, through the addition of circuit-to-circuit ties, the integration of DER and DR and the application of advanced communication technology will create a self-healing infrastructure.
- DR programs will be widely expanded and utilized as system resources to assist in the management of system overloads, voltage issues, and stability issues. DR will also be used to support local circuit needs.
- DA will be further expanded and integrated with widespread DER/DR and, in conjunction with new operating and visualization tools, will enable successful dynamic islanding.
- Critical system components will be “hardened” where appropriate, including redundant designs and in-place spares.

These advances will together create a sophisticated self-healing capability in the modern grid that will dramatically improve its overall reliability, efficiency, safety and will also increase its tolerance to a security attack.

Requirements

Key Success Factors

The self-healing principal characteristic is essential to achieving each of the modern grid's key success factors. The ability to detect, analyze and respond to undesirable conditions and events supports these key success factors in the following ways.

Reliable

The predictive nature of the modern grid, coupled with its ability to implement corrective actions in real time, will provide a major improvement in reliability at the transmission, distribution, and consumer level. Advancements in the following areas will enable this:

- Real-time data acquisition of needed parameters.
- High-speed analytical tools that can determine system state, identify system challenges both deterministically and probabilistically, and determine options for preventing or mitigating negative consequences.
- High-speed switching and "throttling" devices that can correct system parameters prior to the occurrence of negative consequences.
- Advanced relaying that adjusts to real-time conditions.
- Redundancy and hardening of critical components.

The self-healing feature of the modern grid will go beyond the prevention and mitigation of outages and will include monitoring of system equipment and consumer portals to identify both emerging and actual power quality issues.

- If a low or unbalanced voltage condition occurs on a distribution network, that condition will be monitored and an appropriate corrective action will be taken.
- If harmonics or other sustained or intermittent power quality issues are detected, these conditions will likewise be corrected.

Secure

The same features of the self-healing grid that enable it to improve reliability also enable it to better tolerate security attack and natural disaster.

- Probabilistic analytical tools will identify weaknesses in the modern grid that can be integrated into the overall security plan.
- Self-healing's intelligent networking and DER features make the grid far more difficult to attack.
- The real-time data acquisition capability of the modern grid will immediately detect challenges to its security.
- The real-time response of high-speed control devices will provide rapid response to security attacks.

- Following security challenges, real-time data acquisition and control will greatly enhance the damage assessment process, and significantly reduce restoration times.

Economic

The self-healing feature of the modern grid will optimize the economics for all stakeholders:

- System reliability and power quality will improve, leading to a substantial reduction in losses incurred by business and individual consumers when power is lost.
- Generators, transmission owners and operators, and distribution companies will benefit from a reduction in lost revenues that now occur when the grid experiences high congestion or unplanned outages. Greatly improved restoration times will also provide these stakeholders with economic benefits.
- Consumers will benefit from more efficient energy markets.
- More efficient operation will reduce electrical losses and maintenance costs.

Efficient and Environmentally Friendly

Much of the same data acquired to support the self-healing feature of the modern grid will also provide value to the stakeholders' asset management programs. In addition, the self-healing characteristic supports a range of environmental benefits.

- Real time data will be used to more effectively load assets in real time and manage their condition.
- Equipment failure prediction/prevention will reduce the environmental impact associated with such events as transformer fires and oil spills.
- The self-healing grid will accommodate all forms of generation, including many green technologies that produce zero emissions. Both health and environmental stresses are diminished as emissions are reduced.

Safe

The self-healing feature of the modern grid includes the capability and intelligence that promotes the safety of workers, consumers, and other stakeholders. In addition, by reducing outages and area blackouts, associated safety issues are mitigated as the exposure of hazards to workers and the public is reduced.

OBSERVED GAPS

The gap between the current and future states of the self-healing modern grid can be summarized as follows:

- Self-healing in the current transmission system is more advanced than in the distribution system, but opportunities exist to significantly improve both. While individual vendor applications exist for certain self-healing features, no previous initiative has integrated a full complement of transmission and distribution technologies to create a fully self-healing power delivery system.

- The cost to develop and implement the needed changes is high. Addressing this cost will require the alignment of all stakeholders, including the federal government, because many benefits of a self-healing grid are societal in nature. Utilities alone cannot justify the investment to attain the societal benefits.
- Advances are needed in many technical areas (as represented by the modern grid's five Key Technology Areas), including the following:
  - Development and deployment of intelligent electronic devices, including advanced sensors.
  - Development and deployment of DER and DR, as well as their integration and utilization by reliability coordinators.
  - Deployment of DA managed by local distribution reliability centers.
  - Installation of circuit-to-circuit ties to move the distribution system toward a networked topology.
  - Deployment of a ubiquitous communication infrastructure to support the self-healing feature.
  - Development and deployment of new visualization techniques to help operators understand system risk levels.
  - Development and deployment of new control algorithms and new control devices to execute self-healing actions.

DESIGN CONCEPT

The self-healing grid will employ multiple technologies to identify threats to the grid and immediately respond to maintain or restore service.

Probabilistic risk assessment technologies will identify equipment, and systems that are most likely to fail. For example, inadequate vegetation control creates a higher probability of transmission and distribution line failures. Power plants with poor material conditions are at high risk for forced shutdown or de-rating. Such assessments will not just be based on historical records, but on real-time measurements and probabilistic analysis as well.

Given probabilistic assessments for equipment, weather, and load as inputs, real-time contingency analysis engines can determine the overall prognosis of the grid's health. Equipment with high risk of failure can be identified for immediate investigation and even deeper analysis. New operator visualization displays will create a clear understanding of grid capability and levels of risk.

High speed, reliable communications and computing capability is an essential ingredient of the modern grid. The self-healing grid will employ extensive voltage and flow control, along with fault current limiting capabilities. Appropriate local and remote devices, running real-time analyses of electrical events, will issue control signals that address emerging problems. Frequently, the short time interval of such events will require all this to happen without human intervention, requiring improved communication and computing.

Design Features and Functions

The features and functions of the self-healing grid, as described in the following, will be present at all levels of the power system from generating source to load, including regional transmission organizations and distribution utilities.

Probabilistic Risk Assessment

State Estimation and Real-Time Contingency Analysis results will be available within seconds. These results will drive Probabilistic Risk Assessment algorithms, which incorporate real-time condition monitoring, combined with short-term weather and load forecasts, to produce easily interpreted descriptions of impending risks at the interconnect level, Regional Transmission Operator (RTO) level and control area level. Such visualization tools provide an unprecedented understanding of the consequences of multiple failures and by their very nature offer clues to resolution options.

Power Stabilization Techniques

New power stabilization software and hardware will be developed to look for the early signs of, and then prevent, a spreading blackout. While alarms will be initiated for human intervention, automation may take mitigating actions, as determined by control algorithms. Split-second decisions, such as opening tie lines, changing flow patterns or shedding load must be taken before an instability becomes a blackout.

Additional inter-RTO Tie Line capacity will maximize needed power transfer capability during emergency conditions. While many tie lines exist today, some require upgrade to higher capacities and more need to be built.

Distribution System Self-healing Processes

Distribution circuits will have many isolating elements that communicate with each other. By sensing circuit parameters and applying internal logic, these circuits will determine when and where to isolate a fault and restore service to others. This can be done through the closing of optimally selected switches, the injection of distributed generation and energy storage devices, and the management of load levels using DR tools. These actions will take place in a timeframe not possible by human operators. Further, these same isolating elements will monitor and control voltage and power quality.

USER INTERFACE

The self-healing grid is comprised of many sub-systems. Those features and functions dealing with state estimation, probabilistic risk assessment, and major equipment reliability will be accessible to the North American Electric Reliability Corporation (NERC), RTO, and Control Area operators. Distribution Centers will have access to distribution information and relevant transmission information. They will also aggregate energy storage, distributed generation and curtailable load information and pass it along to the relevant RTO and Control Areas for bulk power supply applications.

FUNCTIONAL ARCHITECTURE STANDARDIZATION

Figure 4 shows how substation data can be collected at the substation and used to deliver new self-healing applications involving cascading blackout protection, fast state estimation, real-time problem identification and power quality analysis.

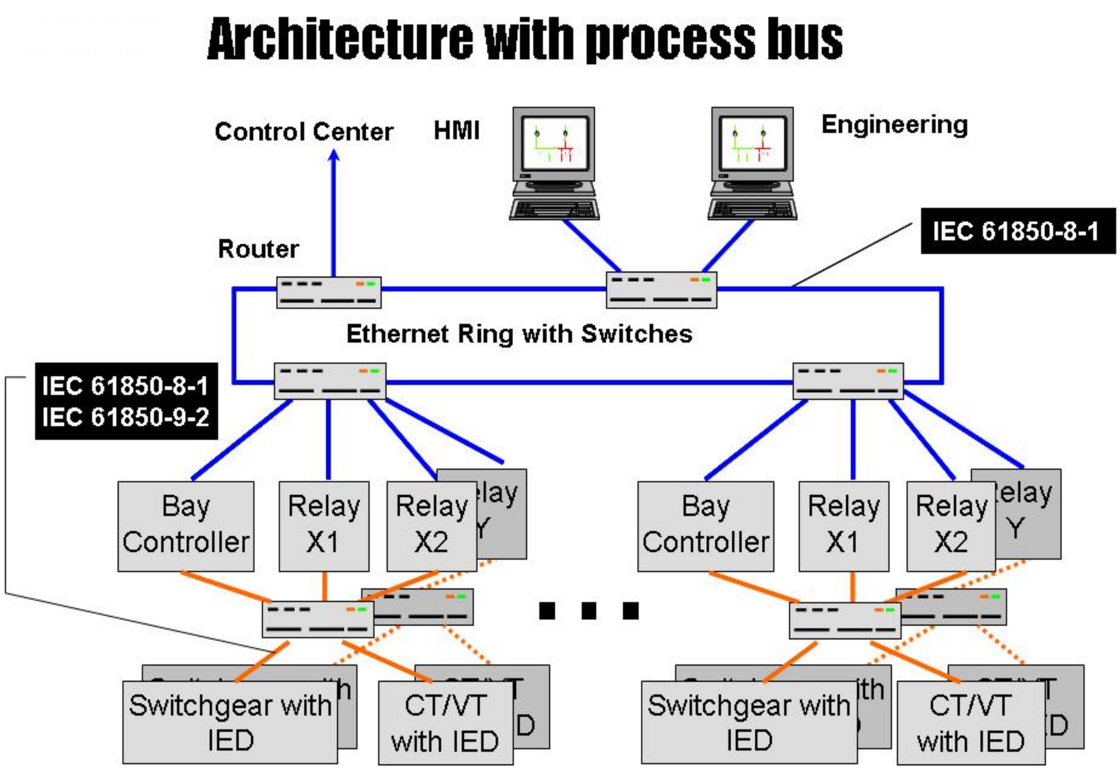


Figure 4: Example schematic of substation data architecture. Image courtesy of International Electrotechnical Commission.

The collection of modern grid data will be placed in a Common Information Model (CIM) format to clearly correlate parameters with the equipment they represent. Standardization on the use of CIM architecture will enable wide transportability as well as fast and easy access to results. The application of CIM Architecture will also extend into the distribution space.

Standardization of communication protocols is another essential enabler of grid modernization. The specific communication technology can be different depending on the application requirements, such as cost and location, but each communications channel must satisfy required security, transit time and quality of transmission.

Reclosers and sectionalizers presently exist on the Distribution System to isolate faults. These switching devices can often be retrofitted with standardized communications, data processing, and actuating devices to make them compatible with the modern grid's requirements.

Performance Requirements

A number of performance measures are required to validate the effectiveness of the self-healing grid. State estimation resolution time and the subsequent real time contingency analysis time are two important metrics. A target of less than 10 seconds is desirable. Additionally, the time to achieve a probabilistic risk assessment with its attendant contingency analysis could follow within a minute.

Existing performance measures recommended for this characteristic include:

- The Customer Average Interruption Duration Index (CAIDI) measures how long it takes a utility to restore service after an interruption and is scored by adding up the durations of each service interruption in a year and dividing the total by the total number of customer service interruptions, thereby deriving the average outage duration for that year.
- The Momentary Average Interruption Frequency Index (MAIFI) is the total number of momentary customer interruptions (less than 5 minutes in duration) divided by the total number of customers, expressed as momentary interruptions per customer per year. MAIFI characterizes the average number of momentary electric service interruptions for each customer during the time period.

Within the modern grid vision, distribution systems become an asset of the control area and the regional transmission organization. The distribution system's load forecast is an important parameter used by control area operators and RTO's. By using distributed generation, energy storage and demand response to manage its deviation from its load forecast, the distribution system would enhance the performance of the transmission system. A metric could be developed to measure how effective the distribution system operators are in meeting their load forecasts.

The identification of distribution reserve is another possible metric and perhaps a new ancillary service. A large reserve would signal a more robust distribution system. The distribution reserve would include both energy (Kwh) and capacity (KW) ratings. The accumulation of many small energy and capacity resources could result in a significant combined energy resource for bulk power system operators.

BARRIERS

Major change usually faces substantial barriers. The modern grid is no exception.

This section discusses the barriers to achieving a self-healing grid.

- **Financial Resources** –The business case for a self-healing grid is good, particularly if it includes societal benefits. But regulators will require extensive proof before authorizing major investments based heavily on societal benefits.
- **Government Support** -- The industry may not have the financial capacity to fund new technologies without the aid of government programs to provide incentives to invest. The utility industry is capital-intensive, with $800 billion in assets, but it has undergone hard times in the marketplace and some utilities have impaired financial ratings.
- **Compatible Equipment** – Some older equipment must be replaced as it cannot be retrofitted to be compatible with the requirements of the self-healing characteristic. This may present a problem for utilities and regulators since keeping equipment beyond its depreciated life minimizes the capital cost to consumers. Early retirement of equipment may become an issue.
- **Speed of Technology Development** – The solar shingle, the basement fuel cell, and the chimney wind generator were predicted 50 years ago as an integral part of the home of the future. This modest historical progress will need to accelerate. Specific areas that will need to be more fully developed and deployed include:
  - Integrated high-speed communications systems.
  - Intelligent electronic device's (both front end sensors and back end control devices)
  - Distribution automation schemes to provide distribution level self-healing capabilities, to accommodate all forms of DER and to act as an asset to the transmission system.
  - Cost-effective environmentally acceptable Distributed Energy Resources, including energy storage devices capable of existing among residential populations.
  - DR systems using real-time pricing.
- **Policy and Regulation** – Utility commissions frequently take a parochial view of new construction projects. A critical circuit tie crossing state boundaries has historically met significant resistance. The state financing the project may not always be the one benefiting most from it. Unless an attractive return on self-healing and other modern grid investments is encouraged, utilities will remain reluctant to invest in new technologies.

- **Cooperation** – The challenge for 3,000 diverse utilities will be the cooperation needed to install critical circuit ties and freely exchange information to implement modern grid concepts.

BENEFITS

The benefits of implementing a self-healing grid are many and diverse, providing benefits to consumers, utilities, employers and government.

The following list is representative of the types of gains that can be expected.

- **Improved Reliability** - Resolving the gaps noted previously will enable a substantial improvement in grid reliability. The cost of power disturbances to the U.S. economy is significant (on the order of $100 billion). The savings from a massive blackout is estimated on the order of $10 billion per event as described in the *'Final Report on the Aug.14, 2003 Blackout in the United States and Canada'*. Since blackout events are increasing in frequency, it is not unreasonable to assume another one will occur within a few years.
- **Improved Security** - A self-healing grid is almost, by definition, the most secure grid. A grid that self heals is a less attractive target since its resiliency reduces the impact an attack can inflict. Also, the consequences of an attack are reduced because energy sources are distributed and self-healing technologies can restore service during and after an attack.
- **Safety -** Increased public safety will be a benefit of the modern grid. Grid re-configurations will quickly de-energize downed wires. Restoring power faster to more people will reduce the impact to customers who rely on the grid for medical necessities as well as maintaining HVAC to elder care facilities. Also, fewer outages reduce the opportunities for criminal acts and civil disturbances.
- **New Revenue** - The installation of DER and DR will create peak shaving and the accumulation of reserves. Both are commercial products in the energy market that can produce revenue streams for their owners.
- **Quality** - The self-healing grid will detect and correct power quality issues. Power quality issues represent another large cost to society, estimated to be in the tens of billions of dollars. In addition, the quality of decisions will improve and autonomous control will occur more quickly.
- **Environmental** - The self-healing grid will accommodate multiple green resources, both distributed and centralized, resulting in substantial reductions in emissions. In addition, the environmental impact associated with outages and major equipment failures will be dramatically reduced. And a more efficient grid means lower electrical losses (hence lower emissions).

RECOMMENDATIONS

Thoughtful, deliberate, concise actions of change are required to enable the self-healing grid to become a reality. This section outlines the recommendations that will help to achieve the self-healing vision.

Many of the individual components, hardware and software, already exist for self-healing features to become a reality. But the integration of all the elements to form a unified single purposed entity still remains to be done.

A clear vision for the modern grid and a transition plan to accomplish it is needed to successfully implement the self-healing feature.

The self-healing characteristic is enabled by each of the five Key Technology Areas. Hence progress must be encouraged in all five. Most essential is the Integrated Communications key technology area, which provides the foundation for all self-healing features.

Demonstration projects of untested and previously never-before integrated technologies are necessary to provide a platform for broader deployment. Technologies that have never been integrated with other technologies in a system context need to be integrated and tested to provide the realistic, business-case quality data needed to cause broader deployment of the technologies.

Many benefits of a self-healing grid accrue to the society in general. The public is the beneficiary whether the benefits are environmental, national security, safety, economic or other. Legislators and regulators must recognize these public goods so that the utility industry has the incentive to move forward.

SUMMARY

The health of an electric system, like that of the human body, is determined in large part by the strength of its immune system—by its ability to heal itself. And in that context, the North American grid's immune system is not especially strong.

Today, there are ways to strengthen this system, to improve its ability to detect and fight off stress. Modern technology can make it much more resistant to the challenges of a 21st century society. Today's advances in computers, communications, materials and chemistry have yet to be applied in a meaningful way to this task. That is what can and must be done.

There can be no doubt that a prosperous society is built upon a healthy electric power infrastructure. This is most apparent when that infrastructure is weakened or disabled, as it is during a major blackout. In fact, an extended blackout would have a crippling effect on the fundamental structure of society.

Of course, modernizing the grid infrastructure requires an investment of considerable magnitude. But the resultant benefits, when viewed from a societal perspective, will return that investment many fold.

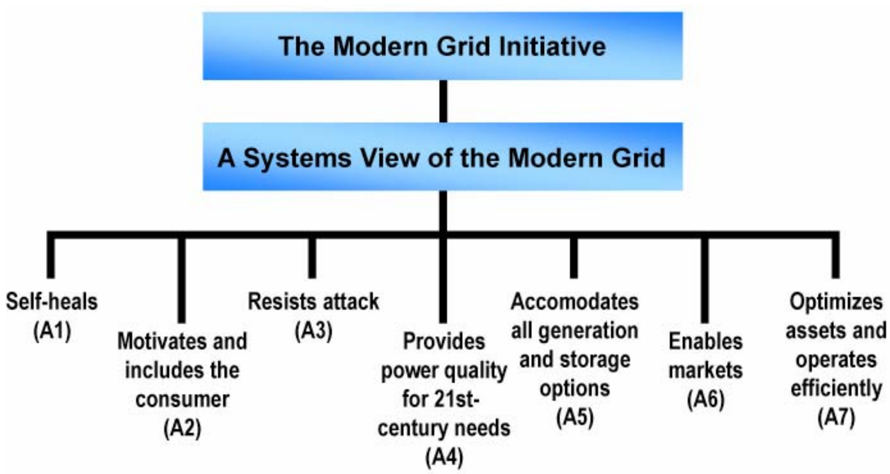
The quest for a self-healing grid will require a coalition of dedicated people determined to make a difference. If you agree with the vision and agree with the conclusions drawn in this paper, we urge you to get involved.

For more information

This document is part of a collection of documents prepared by The Modern Grid Initiative team. For a high-level overview of the modern grid, see “A Systems View of the Modern Grid.”

For additional background on the motivating factors for the modern grid, see “The Modern Grid Initiative.”

MGI has also prepared seven papers that support and supplement these overviews by detailing more specifics on each of the principal characteristics of the modern grid.



Documents are available for free download from the Modern Grid Web site.

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(304) 599-4273 x101

BIBLIOGRAPHY

1. Amin, M. and B.F. Wollenberg "Toward a Smart Grid: Power Delivery for the 21st Century," IEEE Power and Energy Magazine, Vol 3, No 5, Sep/Oct 2005.
2. Amin, M. "Energy Infrastructure Defense Systems," Special Issue of Proceedings of the IEEE, Vol. 93, Number 5, pp. 861-875, May 2005
3. Amin, M. "Toward Self-Healing Energy Infrastructure Systems," cover feature in the IEEE Computer Applications in Power, pp. 20-28, Vol. 14, No. 1, January 2001
4. Amin, M. "Toward Self-Healing Infrastructure Systems," IEEE Computer Magazine, pp. 44-53, Vol. 33, No. 8, Aug. 2000
5. Apt, J., L. B. Lave, S. Talukdar, M. G. Morgan, and M. Ilic. 2004. Electrical blackouts: Repeating our mistakes. Working paper, Carnegie Mellon Electricity Industry Center, CE-04-01.
6. Dukart, J. R. 2003. The future of distribution. Transmission and Distribution World (January), http://tdworld.com/mag/power_future_distribution/.
7. Electric Power Research Institute. 2004. Electricity technology roadmap: Meeting the critical challenges of the 21st century. Summary report, product no. 1010929.
8. Electric Power Research Institute. 2003. The integrated energy and communication systems architecture: Volume II: Functional requirements. Palo Alto, CA: EPRI.
9. Federal Energy Regulatory Commission. 2006. Rules concerning certification of the electric reliability organization; and procedures for the establishment, approval, and enforcement of electric reliability standards. 18 CFR Part 39, Docket No. RM05-30-000, Order No. 672.
10. Glotfelty, J. 2004. Transforming the grid to revolutionize electric power in North America. Presentation to the U.S. Department of Energy Office of Electric Transmission and Distribution.
11. Huber, R. and R. Fanning. 2003. Distribution vision 2010. Transmission and Distribution World (January), http://tdworld.com/mag/power_future_distribution/.
12. Lee, S. T. and S. Hoffman. 2001. Power delivery reliability initiative bears fruit. IEEE Computer Applications in Power 14, part 3: 56–63.
13. Talukdar, S., J. Apt, M. Ilic, L. B. Lave, and M. G. Morgan. 2003. Cascading failures: Survival versus prevention. Electricity Journal 16 (November): 25–31.
14. U.S.-Canada Power System Outage Task Force. 2004. Final report on the August 14, 2003, blackout in the United States and Canada: Causes and recommendations.
15. U.S. Department of Energy Office of Electric Transmission and Distribution. 2003. "Grid 2030": A national vision for electricity's second 100 years.
16. Yeager, K. E. and C. W. Gellings. 2004. A bold vision for T&D. Paper presented at Carnegie Mellon University's Conference on Electricity Transmission in Deregulated Markets: Challenges, Opportunities, and Necessary R&D, Pittsburgh, PA.